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(54) Evaporative Cooling Type Electromagnet

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Specification

1. Title of the Invention
   Evaporative Cooling Type Electromagnet

2. Claims

(1) An evaporative cooling type electromagnet whereby there is overlapping coiling of a wire that has a flat cross-section shape, at least one short side surface of the wire of each layer is enclosed by an annular evaporative cooling jacket to expose these as the coil

external surface so that a cooling medium jacket is formed between said coil external surface and the inner wall surface of the cooling jacket, and the electromagnet is formed by fitting this onto an iron core.

(2) The electromagnet of claim 1 wherein the wire that forms the annular coil is divided in two in the cross-section width direction, and of the two short sides of each divided wire, the short sides of each are in contact with each other, and each of the other short sides are exposed to the cooling medium channel.

(3) The electromagnet of claim 1 wherein a spacer is arranged to maintain the dimensions of said gap between said annular coil external surface and the inner wall surface of the cooling jacket that faces the external surface of said coil, and by extending said spacer along a designated length, said gap is divided along said designated length in multiple vertical channels.

(4) The electromagnet of claim 1 wherein a groove that extends along the length direction of said wire is provided on the inner wall of the cooling jacket of the side that forms the cooling medium channel that faces said external surface of the annular coil.

(5) The electromagnet of claim 1 wherein the annular coil is formed by, with the electromagnet in a correctly positioned state, both end surfaces of the coil standing erect to fit around an iron core, and the coil surfaces for which both short side surfaces of the wire are exposed forming both end surfaces of said coil.

(6) The electromagnet of claim 5 wherein with the electromagnet in a correctly positioned state in relation to the iron core part that is inserted in the inner hole of the annular cooling jacket that holds the annular coil, and the cooling medium channel inside the upper and lower cooling jacket passes through said iron core part to achieve a communication state.

(7) The electromagnet of claim 1 wherein with the electromagnet correctly placed, by having the coil end surface turned down and fitted around an iron core, and having the short side surface of said wire wound as an annular coil which is bent edge-wise so as to form a coil edge, the coil surface for which both short sides surface of said wire are exposed form the inner periphery and external periphery of the annular coil, and the long edge surfaces of the wire of both coil edges form both end surfaces of the annular coil.

(8) The electromagnet of claim 1 wherein there is an iron core equipped with a magnetic pole part that is inserted into the inner hole of the annular cooling jacket that holds the annular coil and a yoke part provided bent on said magnetic pole part, where part of said cooling jacket has at least three sides of its cross section in contact with and surrounded by said magnetic pole part and yoke part, and the other part of the cooling jacket which is positioned symmetrically in relation to the part of said cooling jacket and the magnetic pole part is in contact with the magnetic pole part on one side of the cross section, and the cooling jacket, which is formed with the inner cross section area being bigger than the inner cross section area of said one part, is fitted around an iron core.
(9) The electromagnet of claim 1 wherein a heat radiation fin is provided on the outer surface of the cooling jacket at the part that is not surrounded by an iron core.

3. Detailed Description of the Invention

This invention relates to modifications of an electromagnet in which an electromagnet for generating a magnetic field on the moving body side of a synchronization type linear motor, i.e., a conductor made of desired number of wires whose periphery is appropriately insulated, in other words, an electromagnetic coil made by winding a desired number of coil conductors in which one bundle comprises a desired number of wires a desired number of time one over another (herein after referred to as a "coil"), is inserted in an iron core having an appropriate shape, and is related to modifications on a structure of an electromagnet to efficiently cool all the wires forming said electromagnet.

In a synchronization type linear motor comprising a linear rail as an armature coil and a moving body provided with a magnetic field that moves along this rail by an electromagnetic action, an electromagnet for generating a magnetic field mounted on the moving body is required to have a capability to generate a magnetic field having a required strength as well as to be minimized in terms of the size and its weight. For this reason, a forced cooling is performed on this type of electromagnet to pass a large current, but in cooling the coil, the only thing that can transfer the heat by being in direct contact with a cooling medium is the wires located on the outer surface of the

coil, and the wires that are located inside the coil would transfer the heat indirectly via the wires they are in contact with that have an insulating coating layer on their outer surfaces, and because of the bad heat transfer of the insulating coating layer, a sufficient cooling effect cannot be achieved. For this reason, wires located inside may be prone to either get overheated or burned, and this will quite often cause the maximum operating current to be controlled to be at a small value. In order to deal with this, it is possible, for instance, to consider dividing a coil or to form a coil by providing an appropriate space between wires in order to allow the wires inside the coil to be in direct contact with a cooling medium, but in these cases, a decrease in the ratio of the cross section of the wire's electrically conductive part relative to coil's electrically conductive cross section, i.e., the space factor, will cause the coil to be big, and as a result, the iron core will end up being big for that amount, and an increase in the occupied space and the weight when seen as a whole electromagnet is unavoidable.

The purpose of this invention is to provide a structure of an electromagnet that is modified such that a forced cooling is given to an electromagnetic coil by an evaporative cooling method that enables a high efficiency cooling using a small system structure, and in doing so, at least a part of all of the wires forming the coil can be in direct contact with a cooling medium without sacrificing the above mentioned space factor.

More specifically, in this invention, the electromagnetic coil is formed as an annular coil where an appropriate cross sectional shape that gives a greater space factor of the wire conductor part, for example, a surface where a wire having a flat cross sectional shape is the long side of said wire cross section (hereinafter referred to as a "long side surface") is wound and placed on top of another, and the surface that makes the part that corresponds to the short side that is either a straight line or an arc shape in at least the cross section of each wire that forms the above (herein after referred to as a "short side surface) is exposed and formed as either coil's both end surfaces or inner and external peripheries on both side for every winding layer in terms of the coil winding direction.

In one of the embodiments of this invention, in particular, an annular coil comprising wires where one layer comprises one wound wire is stored in an annular cooling jacket, and when the electromagnet is in a correctly placed state, at least one of the coil surfaces where the above described short side surface is exposed forms an appropriate cross section shape, for example, a gap having a cross sectional shape that is flat vertically, with the internal wall of the cooling jacket.

An evaporative cooling medium is passed through this gap, so the heat generated in each wire forming the coil can be taken away directly and efficiently by vaporized latent heat of the cooling medium, not by the heat transfer to the cooling medium via other adjacent wires as in the case that is not according to the present invention, because either both surfaces or one surface of the short side surface of each wire can be in direct contact with the cooling medium, and thus the temperature rise of individual wire forming the coil can be controlled efficiently. Whether the above described gap that becomes a channel for the cooling medium should be provided on both sides of the coil's cross section or one of the sides can be appropriately selected in view of the amount of heat dissipated from the wires, the size of the cooling jacket, the allowable space occupied in the entire electromagnet, weight and so forth. The intensity of the magnetic filed generated by the electromagnet is proportional to the product of the number of turns of the above mentioned coil and the exciting current, and the electromagnet of this invention can give a greater exciting current density than the case that is not according to the present invention, thanks to this high efficiency cooling effect, and therefore, the coil's cross section can be reduced to achieve a required magnetic field intensity, which will contribute to miniaturization and reduction in weight of the electromagnet.

The specific structure as well as the effect of this invention will be described in detail as follows along with the drawings showing embodiments.

In Fig. 1, Fig. 2a as well as Fig. 2b, the annular coil (1)(1) are stored in the annular cooling jackets (2)(2), and a part of each of them is fitted in the iron core (3) having a cross section that is partially open so that a parallel magnetic flux is generated between the opposing magnetic pole surfaces (4)(4) of said iron core. As the Fig. 2b shows a one turn portion of a coil conductive body in which a wire is not divided, coil (1)(1) is made by winding the wire (5) that has a flat cross sectional shape, and the periphery of said wire (5) is appropriately electrically insulated. The long side surface of the cross section of the wire is placed on top of another at the long side surface when it is wound around a coil, and for each winding, both of the short side surfaces are exposed as the end faces of an annular coil. In other words, in this embodiment, the dimension of the thickness of the annular coil in the axis center direction is formed by the width dimension of the wire (the length of the long side of the wire cross section), and for every layer of wound wire, both of the short side surfaces form the both end faces of the annular coil. When the coil (3) is stored inside, the cooling jacket (2) forms gaps (6)(7)(8) that are communicated with each other in between coil's both end faces and periphery with its inside wall, and the inside wall that is in contact with the magnetic pole portion 9 of the iron core is in contact with the inner periphery of the annular coil (1) and also fixes the internal hole that accepts the magnetic pole portion (9) of the iron core (3). The condition shown in Fig. 2a is assumed to be the correct position of this electromagnet, and it is mounted on the moving body as an electromagnet for generating a magnetic field in this state, and a synchronization type linear motor is formed by placing an armature coil (not shown) from below such that the electromagnet is straddling the gap between both coils (1)(1) and the magnetic pole surfaces (4)(4). A cooling medium such as freon is condensed by a condenser not shown and is introduced into the cooling jacket (2) with a lower conduit pipe (11), and by vaporizing the cooling medium in said jacket, the heat generated at the coil is taken away by the vaporized latent heat, and the vaporized cooling medium is returned to the condenser through the upper conduit pipe (11). More specifically, the cooling jacket (2) functions as an evaporation trough of the evaporative cooling system, and in this case, for every wound layer of wires of the coil, gaps (6)(7) for forming a channel to allow the cooling medium to be in contact

with both of the short side surfaces are formed between both end surfaces of the annular coil (1)(1) and the inner wall surface of both of the end surfaces of the annular cooling jacket (2)(2) as vertically flat communication channels.

In the embodiment shown in Fig. 2a as well as Fig. 2b, the annular coil (1) is made by winding the surface of the long side of the wire in the radial direction and erected and fitted in the iron core in such condition that the both end surfaces of the coil are formed by both of the short side surfaces for every wound layer of the wire, but the coil does not necessarily have to be wound in this manner, and as shown in Fig. 3a as well as Fig. 3b, coil (1) can be formed such that both of the short side surfaces of the wire are bent edgewise to become an edge so that the long side surfaces are placed on top of another. More specifically, in Fig. 3a and Fig. 3b, wire (5') is bent in a plane that is roughly parallel to the long side surface and wound on top of another in the axis direction of the coil, and thus-formed annular coil (1') is formed such that its external periphery and internal periphery are formed by the short side surface of each of the wound layers, and as shown in Fig. 3a, when the electromagnet is in the correctly placed state, it is fitted in the iron core (3) in the manner that the end surface of the annular coil is placed with its face down in the horizontal plane...Also in this case, an appropriate cross sectional shape, i.e., a cooling medium channel having a cross sectional shape that is vertically flat, is formed by the gaps (6')(7') that are respectively formed between the inner periphery inner wall surface and peripheral inside wall of the annular cooling jacket (2) and between the inner periphery and the periphery of the annular coil, and for every wound layer, both of the short side surfaces of the wires of the coil are made to be in direct contact with the cooling medium that is flowing through said gap (6')(7') . Furthermore, in the embodiment in the above mentioned Fig. 3a and b, if the ratio of the dimensions of the cross section of the wire (long side/short side) is so big that it is difficult to bend it edgewise, it can be divided into left and right as necessary with the chain line (Y1'-Y1), (Y2' – Y2) as the center line of the division to make the above described ratio (long side/short side) small. For instance, when it is symmetrically divided into two, since the cross section of the wire will be 1/2, the amount of the heat dissipated will also be reduced by half,

as long as other conditions such as the current density and so forth are the same. On the other hand, even if the same coil is changed into two coils by dividing it into two as described above, since one of the short side surfaces of the coil wire will always form the coil surface that is in direct contact with the cooling medium for every wound layer, the cooling effect will be effectively no different from the case where an undivided coil is used. Incidentally, it is needless to say that there are cases where the length of the short side becomes longer than the length of the side that corresponds to the pre-division long side as a result of the division into two.

A similar effect is also true with the case where the coil is divided into two in the above-mentioned Fig.2a and b.

Accordingly, even in the case of the coil winding pattern shown in the above mentioned Fig. 2a and b, it is okay to switch to 2 coils made by symmetrically dividing the coil as necessary with the (Y1'-Y1)(Y2'-Y2) line as the center of the division. Further describing it in detail from a different point of view, in this embodiment shown in Fig. 3, even if a gap is not formed between one of the end surfaces of the annular coil on the magnetic pole surface side (4) and the adjacent inner wall surface of the cooling jacket, heat is directly transferred to the cooling medium at the coil's inner and external peripheries, and therefore, said coil end surface and magnetic pole surface can get closer within one plane, and compared to the earlier embodiment, a skewed magnetic flux at the edge of the magnetic pole surface can be reduced, and a magnetic distribution that is uniform within one layer can be generated between the magnetic poles.

In Fig. 3a, at the upper cooling jacket, a gap (8) is formed with the upper end surface of the annular coil whereas at the lower cooling jacket, a gap (8) is formed with the lower end surface of the annular coil, therefore, it is desirable to install the cooling jacket's inlet from the bottom of the upper cooling jacket and also the cooling jacket's outlet from the top of the lower cooling jacket at appropriate locations where they would not stick out too much into each magnetic pole gap, for example, at the front and back of the yoke side (12). In addition, in connection with the structure of this coolant inlet and outlet, to allow

communication between the gaps (6') and (7') at the lower part of the upper cooling jacket and communication between the gaps (6') and (7') at the upper part of the lower cooling jacket, as shown in Fig. 4, for example, by bending the upper coil and the lower coil upward and downward, respectively, at the coil bent part (13) of the front and back of the iron core inside the cooling jacket, the coil side surface at said bent part may be separated from the inner wall surface of the upper and lower ends of the cooling jackets.

In the vertically flat flow channel gaps (6) and (7) or (6') and (7') formed by the coil surface with the short side surfaces of the wire being exposed and the inner wall surface of the cooling jacket (2), a liquefied coolant will evaporate while generating air bubbles, removing the heat generated by the coil by means of the vaporized latent heat. Therefore, in the gaps (6) and (7) or (6') and (7'), air bubbles will rise from the lower side to the upper side, so a region of gas might be created in the upper space. If the short side surface of the wire at the top of the coil is exposed into this gas region, the cooling effect will differ from that on the other part that is immersed in the liquid coolant, and there are cases in which the difference in cooling effect will become a problem, and its possibility will become particularly higher if excitation is done by a large current. In the embodiment shown in Fig. 5, by arranging a spacer (14) extending in the long direction of the wire at the middle height point of gaps (6) and (7), the dimension of gaps (6) and (7) is maintained and the gap is separated into an upper channel and a lower channel. By applying such spacer (14) to the horizontal section (H) of the cooling jacket right below the magnetic pole part (9) in Fig. 1, rising air bubbles can be evenly distributed in the vertical direction in said section (H) where the upper space of the gap is particularly small, and uneven distribution of a large gas region only in the uppermost part can be prevented, thereby achieving a uniformed cooling effect. In the aforementioned horizontal section (H), it is necessary to construct a partition by extending the spacer (14) in the length direction of the wire until it reaches the section right below the iron core because of the reason described above, however, in relation to the diameter of air bubbles to be generated, this function as the partition can be achieved, for example, with this spacer (14) to which small through-holes are made, or by arranging narrow width spacers used at the sections other than the horizontal section in series with a small gap in between just for the horizontal section (H).

For the effective cooling on the coil surface against the aforementioned rising air bubbles, in the embodiment of Fig. 6, a groove (15) is created along the length direction of the wire at the inner wall surface of the cooling jacket that is facing the coil surface with the short side surface of the wire being exposed, so that a uniformed cooling can be achieved by guiding air bubbles into the groove and letting them flow through while keeping them away from the coil surface.

Also, for a vaporized coolant that might be collected in the upper space of the gaps (6) and (7) in the horizontal section (H) right below the iron core, it is also effective to create a path (16) that passes through the magnetic pole part (9) of the iron core and then communicates between both gaps of the upper and lower cooling jackets as shown in Fig. 7.

For each of the aforementioned embodiments, if the heat generated from the coil is relatively small, generation of air bubbles and creation of a gas region resulting from it will not be such a problem, therefore, in this case, it is possible to make the inside of the cooling jacket positioned higher than the magnetic pole part (9) when an electromagnet is in a correctly placed state a gas region to be air-cooled by a vaporized gas coolant from the liquefied coolant inside the lower cooling jacket, and in this case, as shown in Fig. 8, it is desirable to allow a sufficient amount of liquefied coolant to be sent in by increasing the internal cross-sectional area of the lower jacket while reducing the internal cross-sectional area of the upper jacket to increase the flow velocity of vaporized gas coolant, thereby reducing the cross-sectional area of the upper jacket that is disposed inside the space enclosed by the magnetic pole part of the iron core and the yoke part, increasing the percentage of the cross-sectional area of the coil in said space, and avoiding an unnecessarily larger iron core relative to the cross-sectional area of the coil. Also, Fig. 9 is a perspective view of the cooling jacket (2) in an example of Fig. 8 and it is structured such that only the iron core mounting part, in particular, has a small cross-sectional area from the reason described above.

In the example of Fig. 8, the cross-sectional area of the cooling jacket is made larger by using an extra space that is not enclosed by the iron core, however, using this extra space, a heat radiation fin (17) may be installed on the external surface of the lower cooling jacket as shown in Fig.10. This will allow a condenser (heat exchanger) (not

shown.) to be smaller and lighter.

As clear from various aforementioned embodiments, according to this invention, with the evaporative cooling, all of the both short side surfaces of the wire constituting the coil can be cooled by being in direct contact with the cooling medium, at least not via any other wires, so defects in existing products such as overheat or burnout of the specific wire arranged inside the coil due to heat generation cam be eliminated, and furthermore the space factor of the coil conductor part is considerably increased compared to existing products that achieve a similar cooling effect, and a small and light large output electromagnet can be constructed without increasing the size of an iron core, and therefore, as an electromagnet to be mounted on the moving body of the synchronization type linear motor, this can contribute to the reduction of the moving body's own weight

4. Brief Explanation of the Drawings

Fig. 1 is a longitudinal sectional view showing an electromagnet of the first embodiment in this invention, Fig. 2a is a perspective view of the same embodiment including a cross-sectional view, Fig. 2b is a perspective view of the same embodiment showing one turn of the coil, Fig. 3a is a perspective view of another embodiment including a cross-sectional view, Fig. 3b is a perspective view showing one turn of the coil, Fig. 4 a partial longitudinal sectional view of another embodiment, Fig. 5 and Fig. 6 are partial cross-sectional views showing each different embodiment, Fig. 7 is a partial perspective view including a cross-sectional view of another embodiment, Fig. 8 is a partial cross-sectional view showing another embodiment. Fig. 9 is a prospective view showing only the cooling jacket in the previous figure, and Fig. 10 is a partial cross-sectional figure showing another embodiment.

(1): Coil, (2): Cooling Jacket, (3): Iron Core, (4): Magnetic Pole Surface of the Iron Core, (5): Wire Conductor, (6)(7): Gaps, (9): Magnetic Pole Part, (12): Yoke Part, (14): Spacer, (15): Groove, (16): Through-channel, and (17): Fin.

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Figure 1

Figure 2a

Figure 2b

Figure 3a

Figure 3b

Figure 7

Figure 10

Figure 4

Figure 5

Figure 6

Figure 8

Figure 9